fish exhibited the highest mercury concentrations. Additional sampling during 1999 will provide further evidence to evaluate the influence of this parameter on mercury uptake.

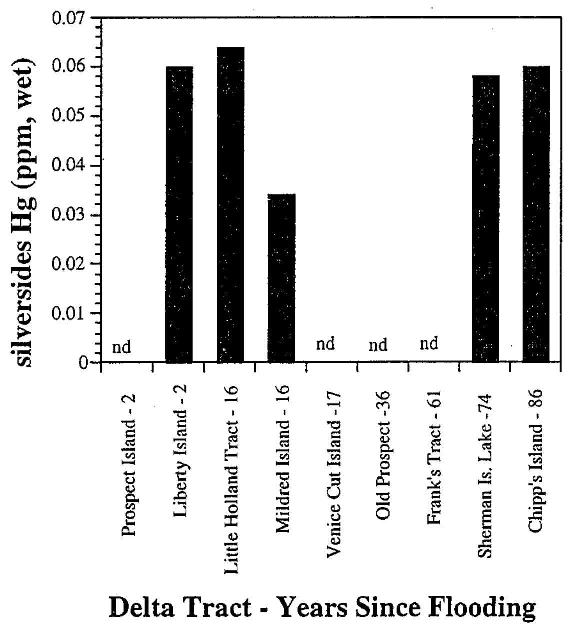

Figure 6 Mercury in silversides as a function of "time since flooding" in Delta tracts. The letters "nd" indicate no data available.

CONCLUSIONS

Contrary to some previous assumptions, preliminary data from a single field season with limited replication suggest that mercury concentrations in biota are not uniform throughout the Delta. In fact they may vary widely, by as much as 10- to 20-fold within taxa and among sites. There are numerous gradients that could contribute to the variability in mercury concentrations in biota among various Delta sites. These potential gradients include source regions of riverine inputs (Sierra compared to Coast Range), chemical composition of mercury sources (originating from different mine sites or different regions within individual mines), time since flooding, salinity, extent of vegetation coverage, plant community or stage of succession, sediment resuspension, speed and direction of current flow and presence of other contaminants, among others. The preliminary results indicate that proximity to key watershed mercury source regions may be an important factor influencing relative mercury bioavailability. Further sampling is necessary to test the significance of these various gradients on the production and bioaccumulation of mercury within various Delta habitats. The next phase in our analysis will also include establishment and sampling from *ex situ* microcosm experiments to determine potential local rates of mercury methylation.

RELEVANCE TO BAY-DELTA MANAGEMENT-LEVEL DECISIONS

Regions demonstrating enhanced mercury bioavailability may not be the most desirable locations for large-scale wetland restoration efforts, particularly if similar habitat options are available at alternate sites. Regions exhibiting relatively low mercury bioaccumulation may suggest sites for alternative restoration and rehabilitation plans. At sites where there is already a commitment for restoration, it may be possible to modify engineering plans to minimize the mercury-related consequences of the projects. For example, alternate levee breeching schemes may be possible at several of these sites, with dramatically lower mercury source water and suspended sediment present on one side as compared to the other. The McCormick-Williamson Tract and Prospect Island appear to offer exactly this type of alternative. These kinds of specific alternatives will be investigated in greater detail in ongoing work. We may also be able to develop additional management options aimed at the minimization of mercury bioaccumulation, both at individual restoration sites and regionally. The initial findings of this project confirm that mercury considerations should be addressed in wetlands restoration plans for the Bay-Delta system.

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LESSONS FROM THE HOME OF THE CHINESE MITTEN CRAB

Zachary Hymanson, DWR, Johnson Wang, National Environmental Sciences, Inc., and Tamara Sasaki, California Department of Parks and Recreation

Since its initial detection in South San Francisco Bay in 1992, major increases have occurred in both the abundance and distribution of the Chinese mitten crab, *Eriocheir sinensis.* Estimates of abundance from crabs entrained at the Central Valley Project Tracy Fish Collection Facility increased dramatically from dozens in 1996 to tens of thousands in 1997 to over three quarters of a million in 1998 (Siegfried 1999). Veldhuizen and Stanish (1999) and Veldhuizen and Hieb (1998) reported the mitten crab has been detected throughout the midsection of the Central Valley from Colusa to Merced, as well as San Pablo, Suisun, and South San Francisco bays, and most of the tributaries to these bays.

The introduction and establishment of the Chinese mitten crab in the Sacramento-San Joaquin Estuary is by no means a unique event. The estuary is described as one of the most cosmopolitan estuaries in the world (Nichols and others 1986), while recent analyses by Cohen and Carlton (1998) document the dramatic rate at which introduced organisms have become established in the estuary with no signs of remission in sight (Figure 1). The mitten crab continues to receive major attention, however, because of its conspicuous presence over a broad area and because of real or potential threats it imposes on the flora, fauna, and infrastructure of the estuary and associated watershed (Table 1). In addition, the California Fish and Game Commission continues to consider the contentious issue of establishing a commercial fishery for the mitten crab, and the impacts such a fishery could have on other native species and neighboring states.

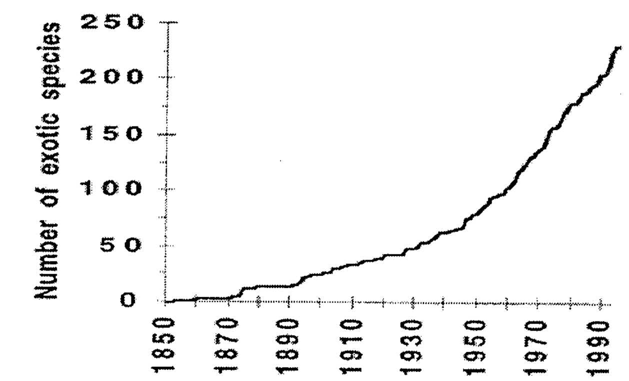

Figure 1 Cumulative number of introduced species established in the Sacramento-San Joaquin Estuary, illustrating the rate of introductions between 1850 and 1990. Total number of species in 1990 is 234. Adapted from Cohen and Carlton (1998).

Limitations in our knowledge of the biology and ecology of the Chinese mitten crab are a substantial constraint to understanding the full extent of any potential impact. Such knowledge is also important to determining appropriate responses, if any, to address the identified concerns. Under this premise we received permission to complete a fact-finding trip to eastern China, home of the mitten crab. In particular, we sought information relating to the real and potential impacts associated with the crab's presence in California (Table 1). Between 7 and 17 May 1999 we visited areas along the Yangtze River between Shanghai and Hefei (Figure 2). We also met with local officials and researchers associated with the Shanghai Fisheries Bureau and the Anhui Province Fisheries Bureau in Hefei. Professor Zhao was our local host and guide during our stay in China. Professor Zhao is the former director of the Anhui Province Fisheries Bureau and director of the Anhui Weiqing Aquatic Products Company, a leading producer of cultured mitten crabs. Over the last 20 years Professor Zhao's research has focused on the biology and culture of the Chinese mitten crab.

Table 1 List of realized and potential impacts associated with the establishment of the Chinese mitten crab, *Eriocheir sinensis*, in California

Factor	*Realized Impact*	*Potential Impact*
Public Health		1. Crabs may be an intermediate host to the oriental lung fluke, *Paragonimus westermani*. 2. Crabs may bioaccumulate some compounds to harmful levels.
Agriculture		1. Crabs may consume rice shoots. 2. Crabs may burrow in the levees of rice fields affecting successful cultivation.
Ecology		1. Crabs may adversely affect other native species through competition or predation. 2. Consumption of crabs may transfer elevated concentrations of some compounds through the food chain.
Infrastructure	1. Large influx of crabs during fall immigration adversely impacts CVP and SWP fish salvage operations (Siegfried 1999).	1. Crabs burrowing into levees and banks may weaken these structures, increasing the likelihood of failure.
Fisheries	1. High crab abundance in commercial bay shrimp catch damages catch and nets.	1. Crabs may compete with the signal crayfish, reducing catch over time. 2. Commercial fishery for the crabs may adversely impact other native species and may promote the crab's introduction into other areas.
Recreation	1. Theft of bait from recreational anglers especially severe during the fall immigration to spawn. 2. Nuisance occurrence in public areas.	

Figure 2 Map of China and neighboring countries. Area of travel included locations along the Yangtze River between Shanghai and Hefei.

This article presents a summary of the information we obtained from our trip to China. It begins with a presentation of general information relating to the distribution and taxonomy, life history, ecology, and human use of the mitten crab in China. The article concludes with a description of information pertaining to real or potential impacts associated with the mitten crab's establishment in California. The Chinese have completed much research on the mitten crab, including the publication of many books and scientific papers. However, much of the information presented to us and included in this article is descriptive in nature.

Distribution and Taxonomy

The Chinese mitten crab is endemic to the east coast of China and coastal areas of Korea. Within China, the mitten crab's native range extends from the southern border with North Korea (approximately 40°N latitude) to Hong Kong (approximately 22°N) (see Figure 2). The crab occurs inland (westward) within lakes rivers terminating along the east coast of China. The Yangtze River is the largest of these rivers (Figure 3), and historically the mitten crab inhabited the lowland sections of the river and tributaries. Much of the research completed on the Chinese mitten crab comes from work conducted on the Yangtze River population, and information presented in this article is based on that population. The native range of the Chinese mitten crab extends north to the Yalu River in South Korea. The mitten crab has been introduced into Vietnam, substantially extending its southern range in Asia.

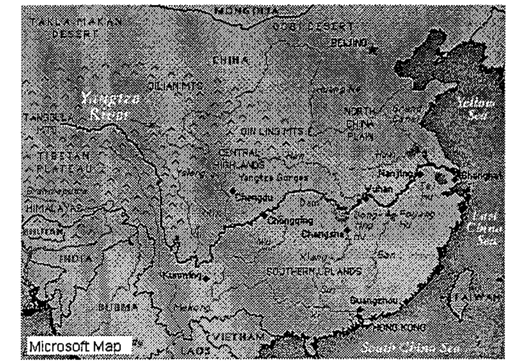

Figure 3 The Yangtze River. The Yangtze River is the largest river in China at about 5,526 km (about 3,434 mi) in length and with a drainage area of about 1,683,500 km^2 (about 650,000 mi^2). Although the entire river is known to foreigners as the Yangtze, the Chinese apply that designation only to the last 645 km (400 mi) of its course. The river has various other names in the provinces it traverses. The official name for the entire river is Chang Jiang, or Long River.

The Chinese mitten crab belongs to the order Decapoda, family Grapsidae, and genus *Eriocheir*. The taxonomy of species within the genus *Eriocheir* is uncertain. Generally, scientists in China recognize four species: (1) *E. sinensis*, (2) *E. japonicus*, (3) *E. leptognathus*, and (4) *E. rectus*. Morphometric variation within a species due to environmental variation throughout its native range is the primary cause of the continued uncertainty, although more recent genetic studies (for example, Li and others 1993) have added to the uncertainty. Two species, *E. sinensis* and *E. japonicus* occur in the Yangtze River. The more prominent notches in the rostrum area between the eyes is the primary phenotypic characteristic used to distinguish *E. sinensis* from *E. japonicus*. (See Veldhuizen and Hieb (1998) for a more complete description of the distinguishing characteristics of *E. sinensis*.) The "mittens" on the claws of the chelipeds are considered a secondary sexual characteristic and are used in the taxonomy of species within the genus. In China, *Eriocheir sinensis* is commonly referred to as the Chinese mitten crab or the Chinese river crab.

Life History

The Chinese mitten crab is catadromous with oviparous females reproducing only once. Mitten crab mating occurs under hard-shell conditions. The development of reproductive tissue can occur in freshwater, but successful fertilization requires the presence of salt water. Most mating occurs in brackish water (10 to 16 ppt). Female fecundity is variable ranging from 250,000 to 900,000 eggs. A detailed account of the mitten crab's life cycle is provided in Veldhuizen and Stanish (1999) and a generalized representation is presented in Figure 4. A comparison of when different life stages occur in mitten crab populations from different parts of the world suggests environmental differences among regions have had little influence on the species' life cycle (Table 2).

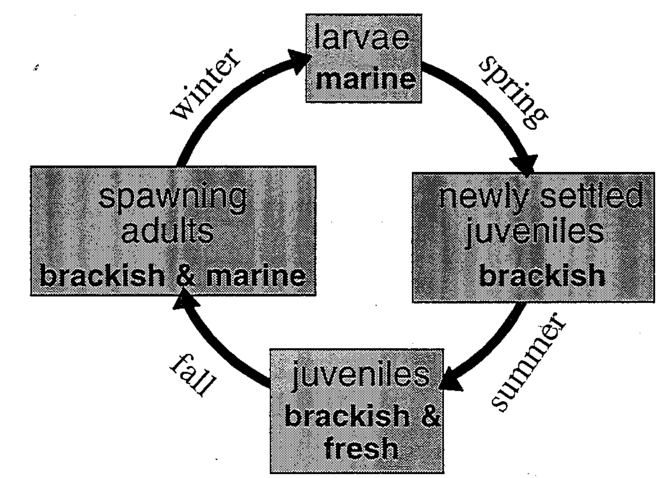

Figure 4 Generalized life cycle of the Chinese mitten crab. Life stage (larvae) is listed above the type of water (marine) where that life stage principally occurs. The season (fall) preceding a life stage (spawning adults) is when the life stage principally occurs. Most juveniles rear one to three years in brackish and freshwater. Juveniles may migrate upstream all year but peak migration occurs in spring.

Table 2 Timing of different life stages of the Chinese mitten crab in three different locations. Data for Europe and the Sacramento-San Joaquin Estuary are from Veldhuizen and Stanish (1999).

Location	*Hatching*	*Settlement*	*Upstream Migration*	*Downstream Migration*	*Spawning*
China (Yangtze River)	January to April	April to June	Year-round, peak out of estuary is May to June	August?, peak is September to October	October to April, peak is in December
Europe	? to July	?	March to July, variable peak among years	August to November, peak is in September	October to January
USA (Sacramento-San Joaquin Estuary, California)	January? to May?	?	Year-round, peak is in summer for age-0, in spring for age-1+	August to January, peak is September to October	November to January?

The maturation rate of mitten crabs varies with the migration distance and rearing location. In the Yangtze River population, 60% of the crabs mature in two to three years, 35% mature after more than three years, and 5% mature after one year. Given the size of the Yangtze River, crabs can spend the majority of their first year emigrating upstream. These crabs tend to spend more time rearing in the upstream areas and have a longer distance to travel downstream to reach salt water. A reduction in water temperature during the fall cues the crabs to begin their immigration back to salt water. Mitten crabs that mature after one year do not emigrate out of the estuary, rearing in areas of low salinity. The presence of salt water is thought to accelerate the sexual maturity of mitten crabs. These crabs are smaller at maturity and have lower fecundity. This strategy of variable maturation rate has several implications to the population biology of the mitten crab. Variation in the maturation rate of individuals within a cohort increases the likelihood of reproduction among individuals of different cohorts. Additionally, this strategy ensures that different portions of the population reproduce each year.

From the information above, we would expect variability in the maturation rate of mitten crabs in the Sacramento-San Joaquin Estuary. Crabs rearing in the tidal channels around the bays and in Suisun Marsh likely reach maturity faster than those crabs migrating to upstream areas of the Sacramento and San Joaquin rivers. Studies of the population dynamics of crabs in this estuary are needed to confirm this hypothesis.

The growth rate of Chinese mitten crabs is inversely related to size. Although the total number of instars is uncertain, it is generally thought crabs molt 10 to 12 times during their first year and three to eight times during their second year. The number of molts continues to decrease in subsequent years. Food availability and water temperature are the most significant factors affecting growth and the frequency of molting. Growth rates increase in the spring and decrease in the winter. Optimal growth under culture conditions occurs between 20 and 30 °C, and growth stops at temperatures below 7 °C and above 30 °C. Under optimal conditions, a crab's body weight can double with each molt during the first year. In China, large mitten crabs are often referred to as "yellow crabs" or "green crabs." Yellow crabs are large sexually immature individuals. Green crabs are large sexually mature individuals. A single molt, the puberty molt, occurs between the yellow and green crab stages. Generally the puberty molt occurs in September with sexual maturity occurring as the crabs migrate downstream to salt water. Most crabs reproduce during the fall, but some hold over until the following spring. Sexually mature crabs from the fall have a more desirable taste and command a higher price than those occurring in the spring.

Ecology

The Chinese mitten crab is considered a temperate-water species of Asia. Rearing crabs are generally found in vegetated, lacusterine (lake-like) habitat and slow moving water. Fast-flowing cold water rivers and streams are not considered suitable habitat for the mitten crab. The lower Yangtze River is ideal habitat for mitten crabs: it is a long freshwater drainage with warm, slow moving water, and a large estuary. Lacusterine habitat is prevalent along the river and adjacent tributaries, although as discussed below some of this habitat is no longer available to the crabs due to the presence of locks and dams. In addition, the Yangtze River flows from west to east, with the

lower river meandering over about four degrees of latitude (approximately 28°N to 32°N). Thus, climatic conditions are relatively uniform over the portions of the river inhabited by mitten crabs. The Sacramento and San Joaquin rivers run north-south and range over about three degrees of latitude (approximately 37°N to 40°N).

The Chinese mitten crab is an opportunistic feeder with an extremely broad diet. The larvae eat phytoplankton and zooplankton. Newly settled crabs are herbivores, with aquatic plants serving as the primary food source. The crabs switch to omnivorous feeding habits within months after settling, eating insect larvae, snails, and small freshwater shrimp. Mitten crabs become more carnivorous as they mature. The crabs are nocturnal, and under culture conditions they will come out of the water at night to feed on pellet food and small fish distributed along the shoreline of culture ponds. Cannibalism is known to occur under culture conditions but is considered insignificant in the wild population because of spatial separation among the different life stages. Humans are the dominant predator of wild crabs, although some native birds and fish also consume the crabs.

Status of the Wild Population

The Chinese mitten crab population occurring in the Yangtze River was substantial. Based on the amount of historically available habitat, the Yangtze River population was likely among the largest of the crab populations within the native range. Although no estimates of the population size were provided, historically the natural population exhibited large fluctuations in size. An extreme change in the weather patterns (for example, drought or flood) is one factor known to cause fluctuations in the population size. Fluctuations in mitten crab abundance have been noted in three rivers within Germany (Figure 5), suggesting the mitten crab population in California may also exhibit fluctuations in abundance. Beginning in the 1960s, however, the mitten crab population within the Yangtze River underwent a sustained decline with a relatively small population persisting today. Three factors were identified as substantially contributing to the decline of the wild population:

- **Loss of rearing habitat.** The construction of numerous small dams and locks block access to upstream rearing areas.
- **Water pollution.** Chronic discharge of untreated industrial effluent has resulted in a substantial decline in the water quality of many rivers. This problem is particularly apparent along the east coast of China where much of the human population and associated development have occurred.
- **Over-harvesting by humans.** The crabs are harvested at three different life stages: megalopa, juveniles, and adults. Adults are harvested for immediate consumption, while megalopa and juveniles are harvested for grow-out in rice fields, ponds, and lakes. Harvest of juveniles was especially productive, as they are known to congregate over sandy bottom areas in water of 1 to 3 ppt salinity during spring tides in late May and early June. Harvest at reduced rates continues to this day. Harvest efforts between the late 1960s and early 1980s focused on the capture of small crabs for grow-out in culture. However, after 1982 the supply of small crabs decreased even further, while the overall demand continued to increase. This led to a greater emphasis on the research and development of culture techniques. Today, reproduction and grow-out to mature adults are routinely completed under culture conditions.

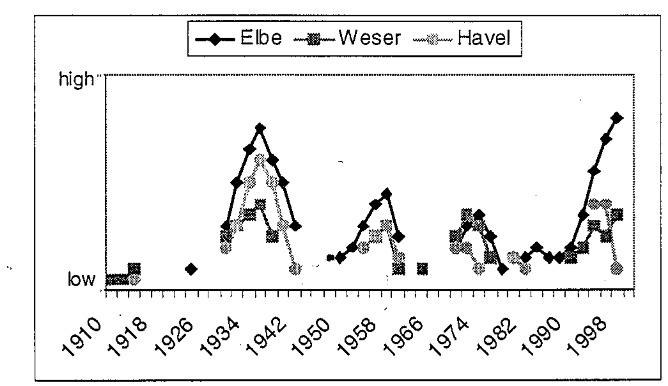

Figure 5 Relative abundance of the Chinese mitten crab in three rivers within Germany since its introduction in 1908. The lines roughly indicate the abundance of mitten crabs based on "semi-quantitative" information from fishermen, waterway authorities, and associated institutions. The data indicate population abundance peaks about every 15 years. Data are from Fladung and Gollasch, unpublished data. Figure is from Gollasch (1999).

The future of the natural mitten crab population in the Yangtze River is uncertain. Efforts are underway to reduce industrial pollution and improve the water quality of the rivers. The commercial harvest pressure on wild crabs is considerably reduced due to poor returns and perfection of culture techniques. However, the availability of freshwater habitat is unlikely to increase.

Human Use

The mitten crab is a highly prized food item consumed throughout much of China and southeast Asia. Human consumption of the mitten crab in China dates back to at least the T'ang dynasty (618 to 907 AD). The reproductive tissue is the most delectable portion of the crab, although muscle tissue is also consumed. Large, sexually mature adults command the highest price. For example, mitten crabs from China in excess of 200 gm each exported to New York for consumption command a price of about $85 per kg, although smaller crabs (<150 gm each) fetch only about $60 per kg. Interestingly, there are regional affinities for the different sexes: Chinese in the northeast prefer males, while Chinese in the southeast prefer females. Chinese in New York and the west coast of California also prefer females. Its demand as a food item combined with a decline in the native population has lead to the establishment of a large aquaculture industry centered between Hefei and Shaghai along the Yangtze River (see Figure 2), with annual revenues estimated at $1.25 billion. Major markets for the sale of adult crabs include Shanghai, Hong Kong, Canton, Singapore, and New York City. Sustained demand and successful aquaculture have lead to the introduction of the mitten crab into many areas of China outside its native range.

Real and Potential Impacts

Presented below is information obtained from China relating to real or potential impacts associated with the mitten crab's establishment in California (see Table 1). Information was presented to us on impacts to public health, agriculture, ecology, and infrastructure.

Public Health

We obtained no evidence that the Chinese mitten crab is an intermediate host for the oriental lung fluke, *Paragonimus westermani*. To the contrary, all of the people we spoke with said the mitten crab is not a host for this parasite. Although they have received reports of mitten crabs infected with the lung fluke from Canada and Hong Kong, no substantiating evidence has ever been provided. Another group of crabs, the Chinese creek crabs are known to carry the oriental lung fluke. Creek crabs spend their entire lives in freshwater and live at higher elevations than the mitten crab. There are 200 to 300 species of creek crabs in China, belonging to two different families, Sinopotamidae and Potamidae. Several species in the genus *Sinopotamon* are known carriers of the oriental lung fluke. A freshwater snail, which only occurs in mountain streams, is the primary host of the lung fluke. Mammals such as humans and tigers are the terminal hosts of the parasite. Oriental lung fluke infections in humans apparently occurred with increased frequency during the Cultural Revolution, when uncooked creek crabs were consumed in relatively high proportions due to limited food availability.

We also discussed the potential for mitten crabs to bioaccumulate various compounds to harmful levels. The Chinese only harvest and sell live crabs, as dead crabs are considered of questionable quality. Although the researchers we spoke with were aware of no specific studies on bioaccumulation, many speculated that the molting process might limit the potential for bioaccumulation. One exception may be copper, which is essential to the formation of blood in crabs.

Agriculture

The Chinese mitten crab is routinely cultured in rice fields. Although the mitten crab will consume new rice shoots, this is not a common food item. Consumption of rice shoots is kept to negligible levels by planting the rice first and introducing the crabs once the shoots are several centimeters high. The farmers also provide food for the crabs and regulate the stocking density. The crabs are generally considered a benefit to the rice crop: they consume aquatic weeds and harmful insects that occur in the rice fields, and their waste products are a source of natural fertilizer for the rice plants. The crabs are contained within the rice fields by a one-meter thick perimeter levee with a low fence.

Ecology

Although we only received general information on habitat use by the Chinese mitten crab, we think it is possible to draw some inferences about how those uses may affect the crab's distribution and potential impacts in the Sacramento-San Joaquin Estuary and associated watershed. The crab's extensive use of vegetated habitat and warmer water (20 to 30 °C) suggests we will not find high numbers of crabs in fast-flowing rivers and streams. It has been suggested that mitten crabs may adversely impact salmonid populations in the Central Valley through consumption of eggs and fry. It seems unlikely significant impacts will occur, given differences in the habitats where salmon and steelhead redds are constructed (in other words, cool, fast flowing water) and the habitats where mitten crabs are likely to be most abundant. In contrast, vegetated, perennial shallow water habitat within the Delta is probably suitable habitat for mitten crabs. Thus, we would expect mitten crabs to exploit both existing and restored perennial shallow water habitat in the Delta.

Infrastructure

Burrowing by mitten crabs into banks and levees has been investigated by Chinese researchers at the Anhui Fisheries Bureau. They were interested in using reservoirs for the culture of mitten crabs, and there was concern crab burrowing would weaken the reservoir banks. They found that crabs were most likely to burrow just prior to molting. Since juvenile crabs molt more frequently, burrowing is more common in the younger life stages. The number of burrows generally increased in banks with steeper slopes. Burrowing was lower in banks with vegetation or other forms of cover. The crabs did use rock rip-rap for cover, and there was no evidence of crabs burrowing into the banks behind the rip-rap.

We also discussed the issue of excluding crabs from diversions and intake structures. We described the impacts to fish salvage that occurred in 1998 at the Central Valley Project Tracy Fish Collection Facility (Siegfried 1999) and the State Water Project Skinner Fish Protection Facility. Although the Chinese have not experienced this sort of impact, they were quite fascinated by the situation. Experience from culture operations in China demonstrates the crabs generally follow the path of least resistance and are easily guided by simple structures placed in the water. This information provides support for the crab diversion device proposed for State Water Project Delta facilities. DWR staff is proposing to place a four-foot high K-rail barrier across the approach channel to the fish screens. It is thought that the crabs will move along the barrier up the side of the channel and onto the bank, where the crabs can be removed. Although not proposed at this time, a low barrier placed across the head of Old River in the fall may also reduce the influx of crabs to the fish facilities. Such a barrier may be effective in keeping crabs migrating down the San Joaquin River out of Old River, while allowing for adequate exchange of water.

Conclusions

The information we obtained from China suggests some of the initially suspected potential impacts from the mitten crab's establishment in California may not occur, or may not be as substantial as expected. In particular, potential impacts to public health and agriculture may be relatively minor. Further, ecological impacts in rivers and streams may be less than originally thought. Adverse impacts to levees (especially those with rip-rap) may also be less than expected. However, establishment of the mitten crab in California does come with costs to an already highly invaded ecosystem, but it may be several years before we identify the full extent of these impacts.

Overall our fact-finding trip to China was very beneficial. We obtained a lot of relevant information on the biology, ecology and socioeconomic value of the Chinese mitten crab, established numerous contacts with knowledgeable researchers and aquaculture experts, and obtained several journal articles and books. In time, we hope to have some of these publications translated. We intend to continue exchanging information with our contacts in China. We have also extended an invitation for Professor Zhao to visit us in California in August. This would provide an opportunity for Professor Zhao to examine the Sacramento-San Joaquin Estuary and rivers, meet with others in California working on mitten crabs, and provide direct insights on the mitten crab's future in California.

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Food Quantity and Quality for Zooplankton in the Sacramento-San Joaquin Delta

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This article is part of a series of articles describing the components of a new CALFED-supported, collaborative study of the Sacramento-San Joaquin Delta's foodweb base (see Cloern 1999).

The Sacramento-San Joaquin Delta estuary (hereafter: the Delta) with its great diversity of habitats is home to a wide variety of primary producers including algae, aquatic plants, and riparian vegetation. These primary producers, as well as organic matter brought into the Delta from the surrounding watersheds, provide the food resource for higher-order producers such as aquatic invertebrates and fish. Growth and reproduction of these consumers as well as trophic transfer efficiency in the Delta food web depend to a large degree on the quantity and quality of the available food. Due to the diversity of habitats and primary producers in the Delta, the quantity and quality of food available to consumers is likely to vary greatly.

A direct way to assess food quantity and quality is to measure the growth and reproductive rates of consumers reared on food taken from natural habitats. In our study we feed food particles present in water taken from several Delta habitats to zooplankton. The habitats include river, marsh, floodplain, and flooded island sites and are sampled several times per year. Currently we are conducting these feeding studies with laboratory cultures of the filter-feeding cladoceran *Daphnia pulex*. Due to their rapid asexual reproduction and non-selective feeding behavior, these organisms are well suited to our feeding experiments. We also intend to conduct feeding experiments with calanoid copepods, which are often very abundant in the Delta and an important food resource for fish.

Feeding experiments similar to ours have previously been used in nutritional studies of freshwater cladocerans (Müller-Navarra 1995) and estuarine copepods (Jónasdóttir and Kiorboe 1996). Results from these and other recent studies have shown the concentration of several essential fatty acids as well as elemental ratios (particularly the carbon to phosphorus ratio) in food particles to be strongly correlated with zooplankton production. We are quantifying these and other food and habitat characteristics in cooperation with researchers involved in the larger group project (Cloern 1999; Canuel 1999). To gain further insight into the nature of the food resources utilized by Delta zooplankton, we are also measuring essential fatty acid concentrations and elemental and isotopic ratios in zooplankton collected from our study sites.

The strength and uniqueness of our approach lies in combining the direct assessment of food quality and quantity through feeding experiments with more indirect assessments utilizing numerous field measurements. Results obtained from this study will contribute to a greater understanding of nutritional habitat quality for higher-order producers in general, and for Delta consumers in particular. We also expect to better understand spatial and temporal variability of food quality and quantity for Delta zooplankton. For example, initial results suggest that when flooded, the Yolo Bypass may be a more productive habitat for zooplankton than the Sacramento River, and thus provide richer feeding grounds for young fish. Findings from our study will provide information critical to policymakers and agencies responsible for management of the Delta and its resources.

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Delta Smelt Concerns Result in Changes in SWP and CVP Operations

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State and federal export facility operations were modified in May and June in response to concerns over the distribution and high salvage of delta smelt at the SWP and CVP Delta pumping facilities. Since we have no direct measure of delta smelt losses at these facilities we use salvage of delta smelt as a surrogate for "take." 1999 was an above-normal (San Joaquin Basin) to wet (Sacramento Basin) water year (DWR 1999), but the distribution of young-of-year (YOY) delta smelt was more typical of a dry year hydrology with a greater proportion of the population remaining in the Delta through spring and early summer. It is uncertain why delta smelt remained in the Delta for so long this year, but water temperature may have been an important factor (Dale Sweetnam, personal communication).

Delta smelt spawn in areas of fresh water under tidal influence. In dryer years, spawning is often concentrated on the Sacramento River side of the Delta, especially in the Cache Slough area. In wetter years, spawning is widespread and can occur as far west as the Napa River, as it did this year. Similar to 1997, a large YOY delta smelt population in the central Delta resulted in higher take at the SWP and CVP facilities. The elevated take levels were surprising since this year's Delta hydrograph showed a similar pattern to 1996 (Figure 1). Delta exports were considerably higher in late May and June 1996 than they have been this year, yet delta smelt salvage in 1996 was less than half of the 1999 levels (Figure 2).

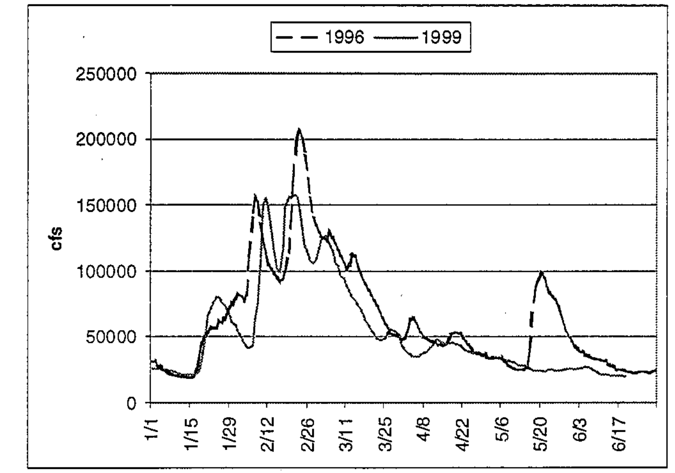

Figure 1 Delta inflow in 1996 and 1999

The US Fish and Wildlife Service biological opinion dealing with the effects of SWP and CVP operations on delta smelt uses two levels of combined SWP and CVP delta smelt salvage as triggers to initiate actions to reduce water project impacts on delta smelt. These thresholds include the following:

- The 14-day running average of combined delta smelt salvage, commonly referred to as the yellow light level.
- The cumulative total of combined salvage for each month, commonly referred to as the red light level.

The red light level is based on historical salvage data and varies among months and among water year types. For example, in an above-normal water year (like 1999) the red light level ranges from 733 fish in December to 11,990 fish in October. Monthly red light levels for below-normal water years are generally higher than for above-normal water years.